ENODISE Workshop



Publicly available documented validation benchmarks

ENabling Optimized DISruptivE airframe-propulsion integration concepts – GA 860103

3 generic configurations for 3 kinds of integration problems

- **BLI**

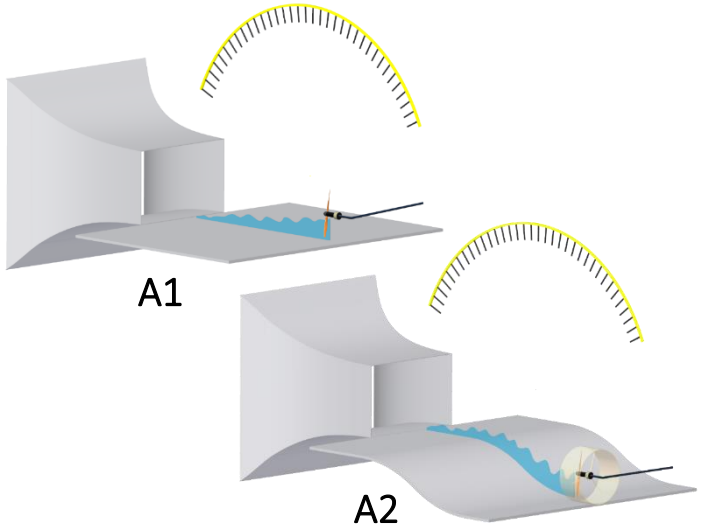


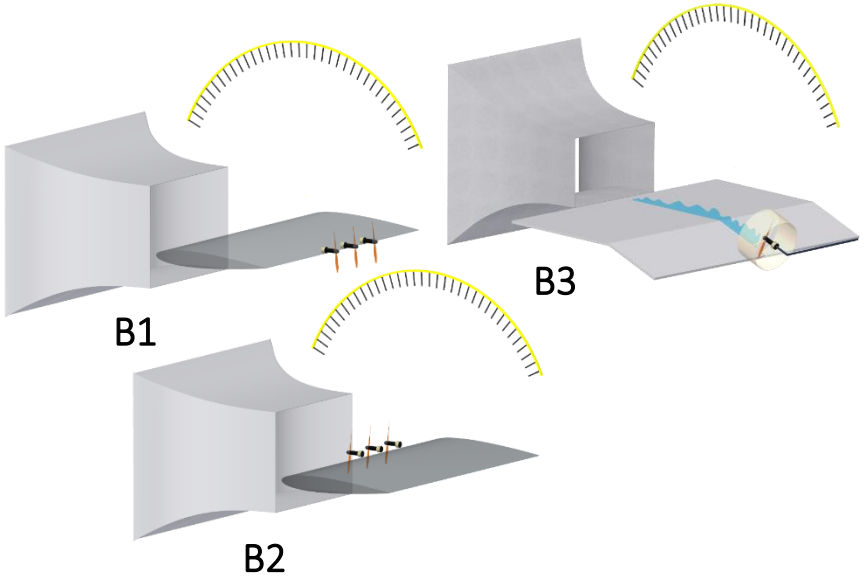
- **DEP**

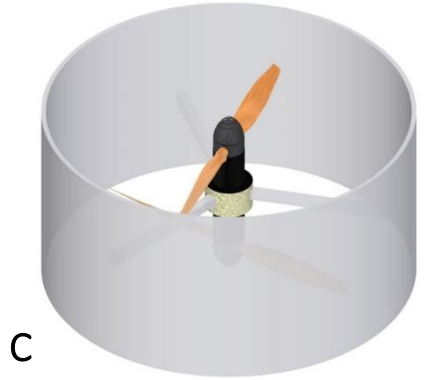


- **Tandem rotors**



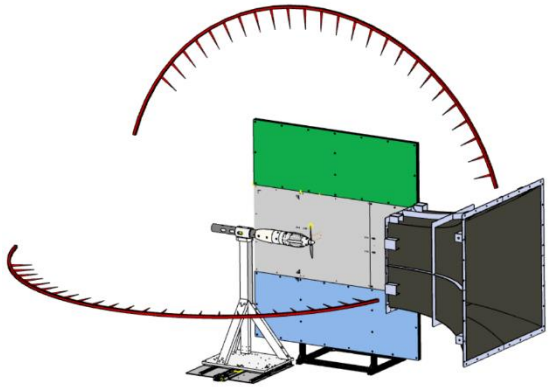






Boundary Layer Ingestion – Config. A1 – Experimental

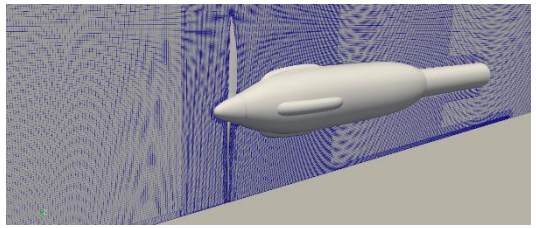
Wall-mounted and buried propulsion systems (infinite-chord airframe) interacting with a flat plate

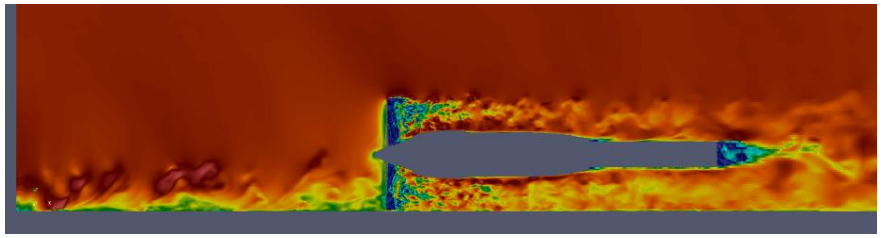


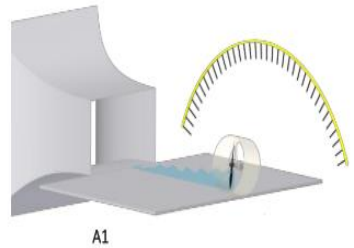
	Aerodynamics		Acoustics	
What	1. Mean velocity and turbulence profiles, two-comp. mean/instantaneous velocities, 2. Cp pressure field, 3. unsteady pressure, 4. propeller thrust and torque.	1. Mean velocity and turbulence profiles, 2. wall-shear stress, 3. Mean velocity, turbulence intensity and Reynolds stresses fields, 4. Torque, power and thrust.	1. Far-field acoustics.	1. Acoustic far-field measurements, 2. beamforming array measurements.
How	1. HWanemometry, 2. pressure taps, 3. surface microphones, 4. load cells.	1. HWanemometry, 2. remote probe, 3. PIV, 4. 2-axes load cell.	1. Far-field microphones in arc shape.	1. Polar array of 16 microphones, 2. array of 64 microphones.
Where	Several positions inflow, across and outflow of the propeller.	At several positions upstream of the propeller and across the propeller plane.	1. Parallel and orthogonal to plate.	1. 1.5 m distance from propeller, every 12 degrees, 2. source grid over the rotor plane.
Who	UBRI	UTWE	UBRI	UTWE
Status	Completed	In progress	Completed	In progress

Boundary Layer Ingestion – Config. A1 – Numerical

Wall-mounted and buried propulsion systems (infinite-chord airframe) interacting with a flat plate



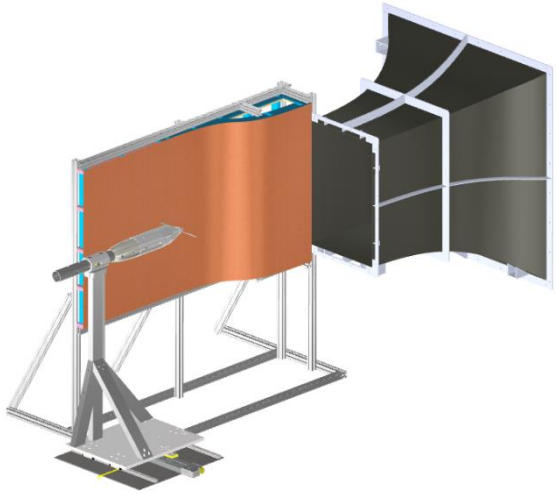




	Aerodynamics			Acoustics		
What	Space-time flow field	Space-time flow field	Space-time flow field	Space-time acoustic field	SPL, PWL, OASPL	Space-time acoustic field
How	GPULES	ZDES + wall model	RANS	FWH analogy	Volume resolving CCA	FWH analogy
Where	CFD domain	CFD domain	CFD domain	Outside FWH surface	CAA domain	Far-field / Microphone positions
Who	GPUP	ONERA	DLR	GPUP	DLR	ONERA
Status	In progress	Starting	In progress	In progress	In progress	Planned in 2023

Boundary Layer Ingestion – Config. A2 – Experimental

Wall-mounted and buried propulsion systems (infinite-chord airframe) interacting with an S-shaped plate



	Aerodynamics	Acoustics
What	1. Mean velocity and turbulence intensity profiles, 2. wall shear stress, 3. mean velocity, turbulence intensity and Reynolds stresses fields, 4. torque, power and thrust.	1. Far-field acoustics.
How	1. HWanemometry, 2. remote probe microphones, 3. PIV, 4. 2-axes load cell.	1. Far-field microphones in arc shape.
Where	1. & 2. At several positions upstream of the propeller, 3. two planes parallel and perpendicular to the rotor plane.	1. Parallel and orthogonal to plate.
Comments	For fixed rotation speeds and variable wind tunnel velocities, and vice-versa; for varying propeller-wall distances.	
Who	UBRI	UBRI
Status	In progress	In progress

Boundary Layer Ingestion – Config. A2 – Numerical

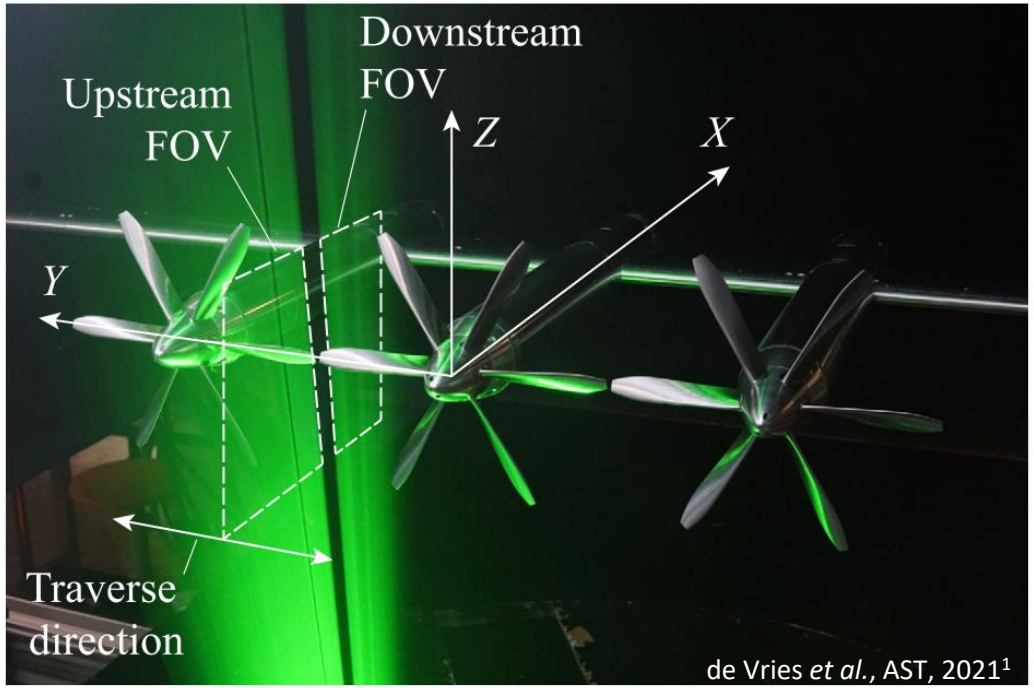
Wall-mounted and buried propulsion systems (infinite-chord airframe) interacting with an S-shaped plate

	Aerodynamics		Acoustics	
What	Space-time flow field	Space-time flow field	Space-time acoustic field	SPL, PWL, OASPL
How	GPU LES	RANS	FWH analysis	Volume resolving CCA
Where	CFD domain	CFD domain	Outside FWH surface	CAA domain
Who	GPUP	DLR	GPUP	DLR
Status	In progress	In progress	In progress	In progress

Distributed Propulsion System – Config. BI – Experimental

Array of three propellers installed in close proximity without the presence of a wing





de Vries *et al.*, AST, 2021[1]

	Aerodynamics
What	1. Pointwise velocity and total pressure, 2. velocity field.
How	1. 5-hole probe, 2. stereo phase-locked PIV.
Where	1. 1 plane between propellers axes (from 0.2R to 1.4R), and 2 planes downstream the propellers disks (at 0.2R and 1.2R), 2. 2 planes (10 x 12 cm2 upstream; 10 x 16 cm2 downstream), translating from 0.5R to 1.4R, with steps of 5 mm in the inboard region and 1.8 mm near the tip (total of 26 planes).
Comments	Characterize propeller slipstream and flow around rotor disk.
Who	TUD
Status	Ready

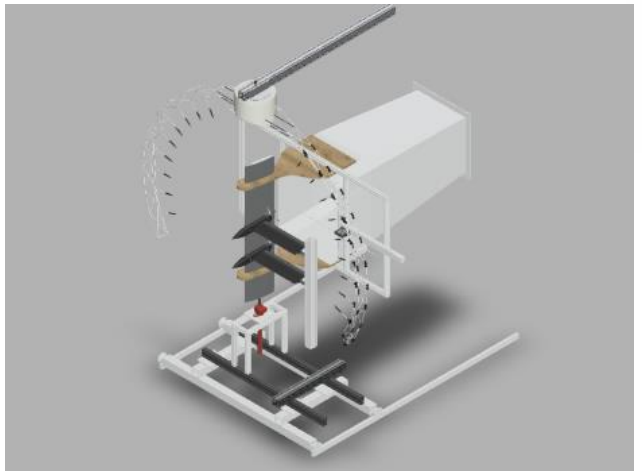
Distributed Propulsion System – Config. BI – Numerical

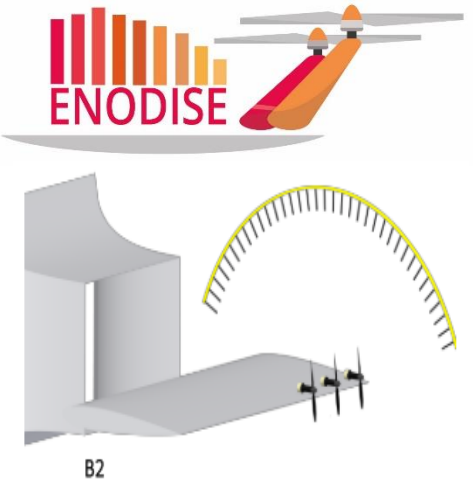
Array of three propellers installed in close proximity without the presence of a wing

	Aerodynamics		Acoustics		
What	Space-time flow field	Turbulent length scales, velocity and pressure spectra, force coefficients	Space-time acoustic field	Time-resolved acoustic pressure	SPL, PWL, OASPL
How	GPU LES, also GPU LES coupled with Multipoint Approximation Method for preliminary aeroacoustic optmization	Wall-resolved LES	FWH analogy	Computational aeroacoustic approach	Computational aeroacoustic approach
Where	To be decided	To be decided	Outside FWH surface	Microphone positions	Microphone positions
Who	GPUP	RWTH	GPUP	RWTH	DLR
Status	Starting	In progress	Starting	In progress	In progress

Distributed Propeller System, Puller Conditions – Config. B2 – Experimental

Array of three adjacent propellers installed over the trailing edge of a wing

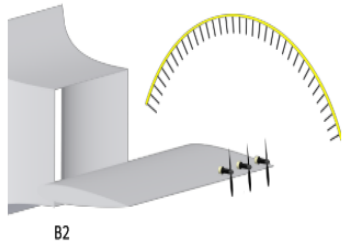




	Aerodynamics	Acoustics
What	1. Mean velocity and total pressure, 2. pressure field, 3. torque, power, and thrust.	Acoustic far-field measurements
How	1. Probe and HWanemometry, 2. Pressure taps, 3. 2-axes load cell.	Rotating array (semi-sphere) of 18 microphones
Where	1. Downstream of the propeller and perpendicular to the rotation axis, 2. chordwise and spanwise, 3. on the propeller support.	2 m distance from propellers
Comments	Characterize propeller slipstream and measure surface wing pressure	Locate dominant sources for characterize scattering noise
Who	ECL	ECL
Status	Starting soon	Starting soon

Distributed Propeller System, Pusher Conditions – Config. B2 – Numerical

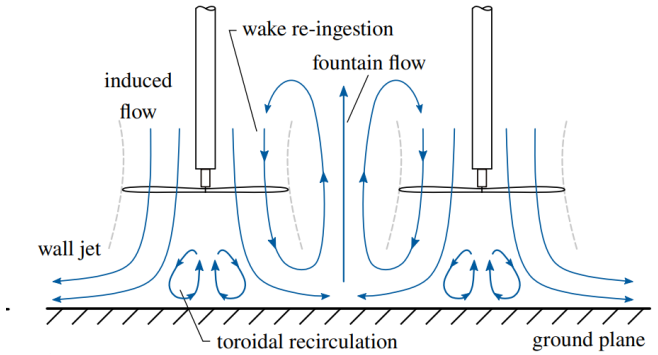
Array of three adjacent propellers installed over the trailing edge of a wing



	Aerodynamics	Acoustics
What	Space-time flow field, turbulent length	Space-time acoustic field
How	GPU LES, also GPU LES coupled with Multipoint Approximation Method for preliminary aeroacoustic optmization (GPUP), wall-resolved LES (RWTH)	FW-H analogy (GPUP), Computational Aeroacoustic approach (RWTH)
Where	CFD domain	Outside FW-H surface (GPUP), microphone positions (RWTH)
Who	GPUP, RWTH	GPUP, RWTH
Status	Starting	Starting

Multi-Rotor Flat-plate Interaction in Hover – Config. B3-eVTOL- Experimental

Two 6-bladed off-the-shelf propellers positioned over a flat plate in hover





	Aerodynamics
What	Instantaneous and time-averaged volumetric velocity field of a side-by-side rotor configuration for various height-to-ground and rotor-to-rotor separation distance.
How	Tomographic Particle Tracking Velocimetry using Helium Filled Soap Bubbles. Grid reconstruction performed by Gaussian Binning for the time-averaged flowfield and VIC+ for the instantaneous flowfield. The 3D-PTV field is extracted at a frequency of 2000 Hz over a sample time of 1s.
Where	Volume of 200 x 310 x 330 mm3 surrounding the propellers and the slipstream between the ground and the propellers.
Comments	• Characterize slipstream conditions during vertical take-off conditions of multi-rotor configurations. • Investigation of the flow topology of the fountain flow and associated re-ingestion.
Who	TUD
Status	Ready

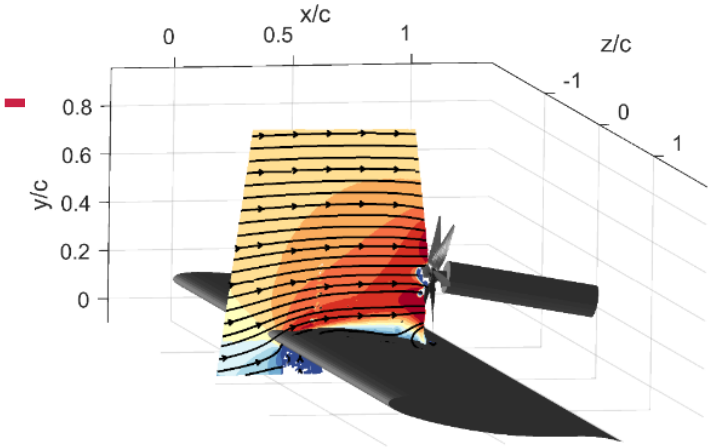
Multi-Rotor Flat-plate Interaction in Hover – Config. B3-eVTOL - Numerical

Two 6-bladed off-the-shelf propellers positioned over a flat plate in hover

	Aerodynamics	Acoustics
What	Space-time flow field	Space-time acoustic field
How	GPULES	FWH analogy
Where	CFD domain	Outside FWH surface
Who	GPUP	GPUP
Status	Planned	Planned

Multi-Rotor Flap Interaction in Hover – Config. B3-Wing - Experimental

eVTOL over-the-wing-propulsion along different phases of the flight envelope



	Aerodynamics	Acoustics
What	1. Mean velocity field, 2. static pressure, 3. propeller thrust and torque.	Acoustic far-field measurements.
How	1. Stereo-PIV, 2. static pressure taps, 3. FUTEK- QSH02113 and FSH04100 torque and thrust sensors.	2D acoustic array consisting of 64 microphones and 3 free-field microphones.
Where	1. Measurement plane 220x220 mm2 over the suction side of the wing, 2. 61 center span positions of the wing, 3. On the motor axis.	• 0.709 meters from the test section, directed toward the suction side of the wing. • 2.12 meters from the test section, directed toward the pressure side of the wing.
Comments	The propeller is: • traversed in span direction for a volume reconstruction of the 3C-velocity field • traversed in span direction to create surface pressure measurements	Sample frequency of 41kHz, sample time of 15s. Also measured the motor 1p signal which allows for phased-locked post processing.
Who	NLR	NLR
Status	Completed	Completed

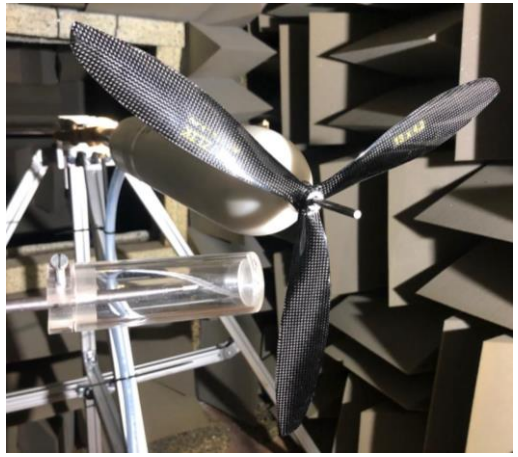
Multi-Rotor Flap Interaction in Hover – Config. B3-flap - Numerical

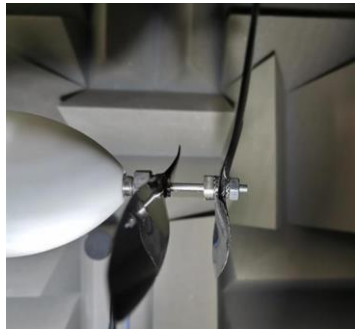
eVTOL over-the-wing-propulsion along different phases of the flight envelope

	Aerodynamics	Acoustics
What	Space-time flow field	Space-time acoustic field
How	GPU LES	FW-H analogy
Where	CFD domain	Outside FW-H surface
Who	GPUP	GPUP
Status	Planned	Planned

Multi-rotor Propulsive Systems – Config. C – Experimental

Co- and contra-rotating propeller system with different number of blades, different rotor-to-rotor spacings, and without a short duct

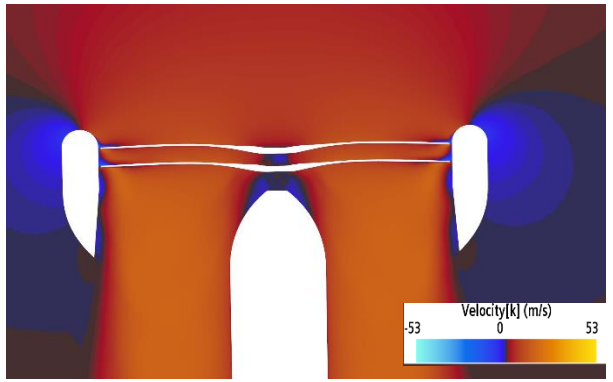




	Aerodynamics	Acoustics
What	Thrust, torque, velocity field, aerodynamic power, wake evolution	SPL, OASPL
How	Load cells, torquemeter, hot-wire anemometry, stereo PIV, encoder	Line of microphone array
Where	Planes parallel and perpendicular to propeller plane, upstream and downstream	Sidelines, near-to-far field
Comments	Inter-rotor measurements if possible	Parametrized clocking and inner rotors spacing
Who	VKI	VKI
Status	Ongoing	Ongoing

Multi-rotor Propulsive Systems – Config. C – Numerical

Co- and contra-rotating propeller system with different number of blades, different rotor-to-rotor spacings, and without a short duct





	Aerodynamics	Acoustics
What	Unsteady velocity field, unsteady blade pressure field, wake evolution of the ducted and unducted system	• Tonal SPL at blade-passing frequency and harmonics including scattering • Broadband SPL
How	URANS simulations with sliding mesh and overset mesh approaches	• Tonal noise assessment via FEM-based solver including scattering (VKI) • FW-H integrals, solid and porous formulations (ONERA) • Broadband prediction via Amiet's theory
Where	CFD domain	Microphone locations defined in the experimental campaign
Comments	Develop optimization strategy focused on blade and duct shape (VKI)	
Who	VKI, ONERA	VKI, ONERA
Status	On going	On going

Thanks for your attention



Questions ?